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(54) BLEACH PLANT CONTROL METHOD

(54)

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ABSTRACT:

CLAIMS: Show all claims

*** Note: Data on abstracts and claims is shown in the official language in which it was submitted.

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Abstract of the Disclosure

A control system for a chlorination plant for paper pulp provides for feed forward control for continuously adjusting the percent applied chlorine to compensate for short and medium term variations in bleach demand of the brown stock. A mathematical model of the process may be adjusted for variable retention time and chlorination temperatures and also accounts for the parallel oxidation and substitution reactions in the bleaching process. A chlorination sensor is also provided which compensates for changes in consistency and has two selected sensing wavelengths.

The present invention relates to a method of bleach plant control and more specifically to a chlorination/extraction control system.

In the paper making process the paper pulp is brightened to a selected target value or Kappa number by bleaching. Kappa number is a measure of the quantity of lignin in the pulp. An essential part of the bleaching process is in the chlorination and extraction stages where chlorine is added to the paper pulp and reacts with the lignin. Lignin is the material in paper pulp which causes its brown appearance and which must be removed to produce white paper or in other words, to produce a Kappa number or brightness of a selected value.

Thus, in theory, it is desired to add the proper amount of chlorine bleach for the amount of lignin present in the pulp currently being inputed into the bleach plant. This inputed pulp is normally termed brown stock. After completing the chlorination and extraction process the bleached pulp has an extracted Kappa or K number which is as close to the target as possible.

Typical bleach plants may have the following stage arrangements

1) CEHD
2) CEDED
3) CEHDED

where

C = chlorination tower
E = extraction tower
H = hypochlorite tower
D = chlorine dioxide tower

If the first two stages, C and E, are controlled precisely,

the control of the later stages is much easier.

One type of bleach control system which has been used in the past is the "black widow" control system as described in an article by Obenshain in TAPPI, January, 1958, Volume 41, No. 1. In the "black widow" system a photometric sensing device located downstream of the clorinator feeds back information as to the brightness or Kappa number of the pulp at that point to control a chlorine valve. However, this system does not adequately control the extracted Kappa number since the point at which the sensing device is located is upstream of the chlorination tower and extractor. Thus, it will not easily or adequately compensate for either ambient temperature changes or changes in retention time of the paper pulp in the chlorination process.

Another approach to chlorination is described in an article entitled "A New Approach to In-Line Control of Chlorination" by Jack Strom and Harvey Weyrich in the periodical Pulp and Paper, March, 1972, and in U.S. Patent No. 3,465,550. This system has essentially the same disadvantages as the "black widow" system.

In addition, both of the foregoing approaches use a proportional plus integral analog controller which produces an unstable control loop. P and I controllers are usually detuned to provide a sluggish response because of the danger of process gain or deadtime increasing; if these increase, the control loop becomes unstable.

All of the conventional control methods for bleach plant control have poor control capabilities which either result in high bleaching costs because

of the excess use of chemicals, and concomitantly pollution problems, and also results in poor control of brightness.

Ideally for perfect control, a pure feed forward system would be used where the amount of lignin in the incoming pulp is carefully measured and the proper amount of chlorine is then added to react with the measured lignin to produce the desired amount of bleaching or brightness. This cannot be done since the amount of lignin cannot be successfully measured.

However, the effect of the chlorine which has been added can be measured. But, again a pure feedback control system cannot be used since the total time for a typical chlorination/extraction process may range from 2 to 3 hours. This includes the time in a chlorine mixer, a chlorine tower and an extraction tower.

It is, therefore, a general object of the present invention to provide an improved control system for a bleach plant.

It is another object of the invention to provide a chlorination/extraction control system which provides improved regulation of extracted Kappa number and hence brightness.

It is another object of the invention to provide an improved method of sensing chlorination.

It is another object of the invention to provide a chlorination sensor in a system as above which automatically compensates for changes in consistency.

The present invention provides a method of controlling the extracted Kappa number of paper pulp in a process having a continuous flow of such pulp through premixing means where a bleaching agent is added and partial bleaching takes place and through reactor means to substantially complete such bleaching said pulp being sus-

ceptible to the concentration of lignin which is unmeasurable by itself which affects said Kappa number and where said pulp is subjected to said bleaching agent in said premixing means and said reactor means which affects said Kappa number said method comprising the following steps: sensing a color value related to said Kappa number after said material has been subjected to said bleaching agent in said premixing means; providing a prediction model which in response to said sensed value, the amount of bleaching agent added, and temperature and retention time in said premixer and reactor means, predicts the future value of said Kappa number after being withdrawn from means relative to the present amount of bleaching agent being added; and comparing said predicted future value after being withdrawn from the reactor means with a set point reference and changing said amount of bleaching agent in response to a lack of comparison.

Figure 1 is a block diagram of both the actual process for chlorination/extraction of paper pulp along with a functional block diagram of the process which the associated computer controls.

Figure 2 is a simplified schematic of the chlorination sensor of Figure 1.

Figure 3 is a set of characteristic curves useful in understanding the operation of the sensor of Figure 2.

Figure 4 is a set of curves useful in understanding the operation of the process of Figure 1.

Figure 5 is a more detailed block diagram of Figure 1.

In Figure 1 there is shown in the process portion 10 a typical chlorination/extraction plant. Portion 11 is either a computer or special purpose

control unit which controls the operation of the plant portion 10.

Specifically, the portion 10 includes a chlorination premixer unit 12 which has as inputs the brown stock paper pulp flow on line 13 and chlorine flow on a line 14 which is controlled by a valve arrangement 16. The percent of chlorine applied to the brown stock, of course, is a major factor in determining the extracted Kappa number or final brightness at the output 17 at the end of the process. The chlorine premixer 12 may have a retention time of 20 seconds to five minutes. The transfer function of the premixer is represented by the mathematical notation G1(z). The z transform function is somewhat similar to a LaPlace transform function except that instead of being a continuous variable the z transfer function is based on periodic samples; e.g., every second.

The output of the chlorine premixer which is normally a continuous flow is fed to a chlorine tower 18 and then to an extraction tower 19 both of which are essentially plug flow reactors. The total transfer function of the combined chlorination/extraction process is represented as G2(z) and represents a time delay of from two to three hours. At the output of the chlorination premixer 12 is a chlorination sensor 21 which senses the color of the partially reacted pulp after having been subjected to the injected chlorine for the retention time of the premixer. The sensor output has been designated DS. The chlorination process continues in the chlorine tower 18. The reaction products are extracted in extraction tower 19 where the final extracted Kappa number is reached.

Referring now to the computer portion 11

of Figure 1, a predictor unit 22 provides a mathematical model which predicts the condition of the pulp leaving the extraction tower 19; in other words, predicts the extracted Kappa number, $\hat{EK}$, based on the current operating conditions. Predicator 22 is responsive to several system parameters: percent applied chlorine, CL, temperature, T, chlorination sensor reading, DS, and the retention times of both premixer 12 and chlorine tower 18. In addition, other operating variables of the chlorination process which are taken into account are the type of pulp and the actual particular characteristics of the processing equipment which includes, of course, chlorine premixer 12, chlorine tower 18 and extraction tower 19. All of these variables including ambient temperature and retention times are represented by the input parameters $\hat{K1}'$ through $\hat{K4}'$. Predictor 22 thus provides on its main output line 23, $\hat{EK}$ or the predicted extracted Kappa number.

A byproduct of the predictor is the brown stock predicted Kappa number $\hat{BK}$ which is actually the amount of lignin in the current incoming paper pulp. This value, of course, cannot normally be measured by ordinary on-line methods. The value of $\hat{BK}$ is very useful in the control of the pulping process which precedes the bleaching process. As illustrated, predictor 22 has as other inputs the brown stock flow and the flow of chlorine. A combination of these two elements with brown stock consistency will provide the percent chlorine (CL) added to the brown stock.

Periodic feedback control of the extracted Kappa number, $\hat{EK}$, from output line 17 is also provided to stabilize the remainder of the control system against slow drift in unmeasurable variables. The initial

extracted Kappa number set point is compared with the actual value and any error drives a predictor update unit 25 designated with a function D2(z). Output 27 of this predictor in essence provides a feedback bias which when combined with the predicted extracted Kappa number, $\hat{EK}$, provides on line 28 a Kappa number updated for slow drifts. This is combined with a line 29 which has the current extracted Kappa number set point or target, the difference then providing an error signal on line 30 to drive a chlorine controller 31. This controller has a characteristic D1(z) which is designated to compensate for the delayed measurement of the chlorination sensor 21. In other words, the controller 31 has a control algorithm D1(z) which is a sampled-data, dead-time compensated control algorithm. The output of controller 31 on line 32 drives the chlorine valve control unit 16 in accordance with the error on line 30.

Delay unit 24 incorporates a mathematical model G2(z) which is the retention time of the entire chlorination/extraction process. This unit enables the operator to easily change the final set point by adjusting the current extracted Kappa number set point. This change must, of course, be delayed by G2(z) before being compared with the actual extracted Kappa number to provide an update.

It is apparent from the foregoing description that the computer unit 11 could be either a special purpose computer, a general purpose computer or a specially designed control unit with the actual functional blocks and lines as illustrated.

From a more theoretical and overall viewpoint, it is apparent that the system as described above

is essentially a feed forward system with respect to the predictor 22 with a delayed measurement of the disturbance variable. This disturbance variable is, of course, the amount of lignin in the brown stock or paper pulp. The controlled variable is the brightness or extracted Kappa number of the brown stock and the manipulated variable is the porcont chlorine added to the brown stock.

Figure 2 illustrates the structural details of chlorination sensor 21. Such chlorination sensor is similar in concept to a moisture sensing device disclosed and claimed in U.S. Patent 3,641,349. The sensor in essence measures the transmission of both visible and infrared light through a window 36 in the pulp transmission line 37 from the chlorine premixer 12. A light source 38 is focused by lenses 39 and 41 and chopped by chopper 42. After being transmitted through the pulp or brown stock which is flowing through the line 37, it is split into two portions by a beam splitter unit 43. One portion is filtered by a filter $\lambda 1$, focused thereafter by a lens 44 and detected by a detector 46. The other portion is filtered by a filter $\lambda 2$, focused by lens 47 and detected by a detector 48. The outputs of both detectors are amplified by amplifiers 49 and 51, demodulated by demodulator 52 and then coupled to predictor 22. Thus, the output of demodulator 52 is DS or the chlorination sensor output.

The wavelengths $\lambda 1$ and $\lambda 2$ are as illustrated in Figure 3 substantially 500 millimicrons and 1075 millimicrons. In other words, $\lambda 1$ is in the visible range and $\lambda 2$ in the near infrared frequency spectrum. The curves of Figure 3 illustrate the transmission

characteristic of the unchlorinated brown stock and the brown stock after chlorination and retention times of both two minutes and 50 minutes. It is apparent that the transmission of the wavelength λ1 will be considerably affected by the amount of brightening or bleaching of the brown stock while the transmission of the wavelength λ2 is unaffected. Thus, the latter wavelength may be used as a reference and when compared with λ1 will provide an indication of the chlorine with the brown stock. It is also apparent that λ1 and λ2, although it is believed that optimum values have been selected, may be varied somewhat from these values to achieve the desired measurement results.

The chlorination sensor will also automatically compensate for consistency changes. This is because the presence of more fibers increases the amount of lignin in the path length of the light being transmitted through the window thus making the fiber mass look darker. This, therefore, results in the controller increasing the chlorine flow.

In the preferred embodiment of the present invention the operation of predictor 22 is based on the assumption that two reactions, namely oxidation and substitution, occur simultaneously in producing the bleaching of the brown stock by the chlorine. This is illustrated in Figure 4 where the amount of chlorine consumed relative to the total reaction time provides substitution and oxidation curves, the total chlorine consumed being merely the addition of these two reaction curves. The substitution curve rises very rapidly relative to the oxidation curve. It is apparent that consideration of these reactions is useful in providing a mathematical model of the

bleaching process. This is especially important where, referring to Figure 1, the chlorination sensor 21 is necessarily located immediately at the output of the chlorine premixer which may have a relatively short retention time. This location is necessary since by minimizing this delay time the control system response to rapid or high frequency changes in brown stock Kappa number is made possible. The retention time will, therefore, fall in the very early portions of the substitution-oxidation reaction curves where the fastest rate of change is occurring. Thus, for an accurate prediction, it is believed that it is preferable to use the parallel reaction model.

Utilizing the parallel reaction model for the purpose of prediction the following assumptions are made:

1. Two reactions, both first order, occur simultaneously. These are oxidation and substitution.

2. Chlorine in aqueous solution is hydrolized according to

$$K_T = \frac{[H^+]\ [Cl^-]\ [HOCl]}{[Cl_2]} \qquad (1)$$

where K_T is the equilibrium constant at temperature "T".

A fraction of the initial lignin of the paper pulp reacts with the molecular chlorine in a relatively fast first order reaction; i.e.,

$$\frac{dLs}{dt} = k_s\ [Ls]\ [Cl_2] \qquad (2)$$

where Ls is the concentration of lignin available for substitution and k_s is a function of temperature described by the Arrhenius equation.

4. The total lignin also reacts with the

hypochlorous acid, HOCl, by oxidation; i.e.,

$$\frac{dL_o}{dt} = k_o [L] [HOCl] \qquad (3)$$

where L is total lignin, L_o relates to the reaction by oxidation and k_o is again related to temperature by the Arrhenius equation.

The stoichiometry of the consumption of Cl_2 and HOCl by lignin is related by

$$\Delta L_c = a \Delta [Cl_2] \qquad (4)$$

$$\Delta L_o = b \Delta [HOCl] \qquad (5)$$

where "a" and "b" are the stoichiometric constants.

The foregoing assumptions can be used to derive a mathematical model which is used by the predictor as shown in Figure 1. For control about a given steady state condition it is assumed that a linearized approximation to the aforementioned model is an adequate representation of the system. This assumption cannot be extrapolated over wide range conditions because the process is not linear. Therefore, the linear parameters used in the linearized approximation model must be updated when a major change in the process conditions occurs.

These linear parameters are functions of wood species, retention times between chlorine addition point and sensor and between chlorine addition point and chlorination tower outlet, pH, temperature (inlet and ambient), extracted Kappa number set point and percent chlorine applied.

Two methods are available to determine the parameters. The first is by plant testing which can be very time consuming if operating conditions vary widely. The second method available to determine the foregoing parameters is by simulation of the process

using a mathematical model.

There are two basic versions of the mathematical model. First, it may be based on a single "pseudo" chemical reaction. The second which is used in the preferred embodiment of the present invention is based on the two foregoing parallel chemical reactions including the effect of liquid phase chemical equilibrium. The model is in the form of a computer program. It is believed that the parallel chemical reaction model provides a better fit to experimental data over the full range of retention times since it accounts for the rapid substitution reaction which is observed in the data during the first few seconds or minutes after chlorine addition. The model itself includes equations (1), (2), (3), (4) and (5).

Initially, the following conditions are set: L, L_s, initial chlorine concentration, K_T, k_s and k_o. K_T, k_s and k_o are calculated from the specified reaction temperature.

The following steps are then performed:

(a) Calculate the actual concentration of Cl_2 and HOCl from the hydrolysis equation (1).

(b) Over the integration interval Δt calculate the amount of lignin reacted by

$$\Delta L_s = k_s [Cl_2] [L_s] \Delta t \qquad (6)$$

$$\Delta L_o = k_o [HOCl] [L] \Delta t \qquad (7)$$

(c) Calculate the values of lignin by

$$L_s + L_s - \Delta L_s \qquad (8)$$

$$L + L - (\Delta L_s + \Delta L_o) \qquad (9)$$

and consumption of Cl_2 and HOCl by equations (4) and (5).

(d) Based on changes in Cl_2, HOCl, Cl^- and H^+ recompute Cl_2 and HOCl for Δt using the equilibrum

equation (1).

(e) Repeat steps (b), (c) and (d) for the desired total time. This time, of course, includes the retention times of the premixer and the chlorine tower. The results of this solution procedure is to calculate the profile of Cl_2 consumption and amount of lignin reacted and therefore the color, DS, of the pulp (which is linearly related to the amount of lignin).

From the foregoing simulation the linear parameters K_1' through K_4' can be derived for any given set of conditions including a change in retention time since the additions of Δt compensate for retention time. Also changes in temperature are compensated since K_T, k_o and k_s are related to temperature. The four parameters are the following:

$$K_1' = \frac{\Delta DS}{\Delta CL} \qquad (10)$$

$$K_2' = \frac{\Delta DS}{\Delta BK} \qquad (11)$$

$$K_3' = \frac{\Delta EK}{\Delta CL} \qquad (12)$$

$$K_4' = \frac{\Delta EK}{\Delta BK} \qquad (13)$$

where CL is equal to the percent chlorine applied, BK is equal to the brown stock Kappa number inputed into the process, EK is equal to the extracted Kappa number, and DS is the digital chlorination sensor output. As illustrated in Figure 1, the four parameters K_1' through K_4' are inputed into the predictor in an off-line mode. At the present time this is believed to be the most satisfactory method although an on-line mode might be used when needed for certain types of processes.

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The prime designations represent the value used in the model which may differ from the "true" values for the process because of unavoidable errors in estimating the parameters. As illustrated in Figure 5 in the actual process shown in block 10 the K's are unprimed and in the computer as shown in block 11 the K and G functions are primed.

More specifically, to determine the parameters K_1' through K_4' from the parallel reaction model, small perturbation computations are carried out. For example, to calculate $K_1' = \frac{\partial DS}{\partial CL}$ the initial values are set in the model and DS is computed at the time, tm - the outlet of the premixer. Then the initial value of CL is changed by ΔCL and DS is recomputed; the difference is ΔDS. If ΔCL approaches zero then $K_1' = \frac{\partial DS}{\partial CL} = \frac{\Delta DS}{\Delta CL}$.

In the linearized version of the mathematical model, the digital chlorination sensor output, DS, and the extracted Kappa number, EK, may be related to the constants K_1' through K_4' by the equations:

$$DS = G1(z)\ K_1\ CL + G1(z)\ K_2\ BK \qquad (14)$$

$$EK = K_3\ CL + K_4\ BK \qquad (15)$$

These may be intuitively derived since in equation (14) the digital sensor output is, of course, related to initial brown stock Kappa number and the reaction of the chlorine with that brown stock. The same is true in equation (15) of the extracted Kappa number, Ek.

The function G1(z) relates to the dead time of the process plus the first order lag response between CL or BK and the output reading of the digital chlorination sensor and may be represented by

$$G1(z) = \frac{L z^{-(N+1)} [(1-M) + M z^{-1}]}{1 - (1-L) z^{-1}} \quad (16)$$

where

$$L = 1 - \exp(-T/\tau) \quad (17)$$

$$M = [(1-L)^{1-m} - (1-L)]/L \quad (18)$$

$$\tau = \text{time constant} \quad (19)$$

$$(N+M)T = \text{deadtime} \quad (20)$$

$$T = \text{sample interval} \quad (21)$$

$$N = \text{integer} \quad (22)$$

$$0 \leq m < 1 \quad (23)$$

The foregoing merely illustrates a z transform function which is similar in the continuous mode to a LaPlace transform function.

From a practical standpoint, instead of predicting the value of $\hat{BK}$ passing the chlorine addition point $(N+1)T$ time ago it is more practical to predict BK which is the predicted brown stock Kappa number lagged by the dynamics G1'(z). G1'(z) would include the process response together with the exponential filtering on the digital chlorination sensor signal.

Thus, rewriting equation (14) in a new format yields

$$DS = G1'(z) K_1' CL + K_2' \hat{BK} \quad (24)$$

Rearranging equation (24) to solve for $\hat{BK}$ gives

$$\hat{BK} = \frac{DS}{K_2'} - G1'(z) \frac{K_1'}{K_2'} CL \quad (25)$$

Rewriting equation (15) to now include the z function gives

$$\hat{BK} = G1'(z) K_3 CL + K_4 \hat{BK} \quad (26)$$

and substituting equation (25) in equation (26) yields

$$BK = \frac{K_4'}{K_2'} DS + CL\, G1'(z) [K_3' - \frac{K_4' K_1'}{K_2'}] \quad (27)$$

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It is apparent referring to the predictor 22 of Figure 5 that equation (25) may be utilized to solve for $\hat{BK}$ and equation (27) for $\hat{BK}$. The solution to equations (25) and (27) is shown in block diagram format in the predictor 22. Note that if it is desired to solve for $\hat{BK}$ the remainder of block 22 need not be used.

Thus, the present invention has provided a feed forward type control algorithm which is designed for maximum dynamic effectiveness by compensating for the inherent time delay between chlorine addition and sensor position. Also the present process easily provides for variations in chlorination temperature and in retention time.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. In a method of controlling the extracted Kappa number of paper pulp in a process having a continuous flow of such pulp through premixing means where a bleaching agent is added and partial bleaching takes place and through reactor means to substantially complete such bleaching said pulp being susceptible to the concentration of lignin which is unmeasurable by itself which affects said Kappa number and where said pulp is subjected to said bleaching agent in said premixing means and said reactor means which affects said Kappa number said method comprising the following steps: sensing a color value related to said Kappa number after said material has been subjected to said bleaching agent in said premixing means; providing a prediction model which in response to said sensed value, the amount of bleaching agent added, and temperature and retention time in said premixer and reactor means, predicts the future value of said Kappa number after being withdrawn from means relative to the present amount of bleaching agent being added; and comparing said predicted future value after being withdrawn from the reactor means with a set point reference and changing said amount of bleaching agent in response to a lack of comparison.

2. A method according to Claim 1 where said value related to said Kappa number is measured after said pulp has been subjected to said bleaching agent in said premixing means for a relatively short time period as compared to said retention time of said reactor means which is a relatively long time period.

3. A method according to Claim 1 where said color

value related to said Kappa number is sensed by measuring the transmission of a selected wavelength of visible light through said pulp, measuring the transmission of a selected wavelength of infrared through said pulp and comparing said two measurements.

4. A method as in Claim 3 where said visible wavelength is substantially 550 millimicrons and said infrared wavelength is substantially 1075 millimicrons.

5. A method as in Claim 1 where said bleaching agent is chlorine which is consumed in accordance with the parallel reaction of lignin with chlorine in both oxidation and substitution modes said reactions being affected by variations in said temperature and retention times said prediction model being responsive to said variations.

6. A method of continuously controlling the injection of a bleaching agent into a moving stream of brown stock for producing a desired brightness in the brown stock such brown stock after said injection being retained in reactor means a predetermined retention time to substantially complete the bleaching and thereafter withdrawn from said reactor at a continuous rate, said method comprising the steps of; sensing the color (DS) of said stock after said bleaching agent is injected but before said stock is placed in said reactor means, predicting the extracted Kappa number, $\hat{EK}$, of said stock after being withdrawn from said reactor based on the current values of percent bleaching agent applied (CL) and the darkness of the brown stock ($\hat{BK}$) by

$$\hat{BK} = \frac{DS}{K_2'} - G1(z)\,\frac{K_1'}{K_2'}\,CL \qquad (1)$$

and

$$\hat{BK} = G1'(z)\,K_3'\,CL + K_4'\,\hat{EK} \qquad (2)$$

where $\hat{BK}$ is the predicted darkness of the brown stock lagged by the dynamics $Cl'(z)$ and substituting equation (1) in (2)

$$\hat{BK} = \frac{K_4'}{K_2'} \quad US + Cl'(z) \; [K_3' - \frac{K_4' K_1'}{K_2'}] \; CL$$

where $Cl'(z)$ is a z type function reflecting lag response with respect to a change in brightness sensed after addition of bleaching agent where

$$K_1' = \frac{\Delta DS}{\Delta CL}$$

$$K_2' = \frac{\Delta DS}{\Delta BK}$$

$$K_3' = \frac{\Delta BK}{\Delta CL}$$

$$K_4' = \frac{\Delta EX}{\Delta BK}$$

said foregoing parameters K_1' through K_4' being derived from a mathematical model based on the parallel reaction of brown substance in said brown stock with said bleaching agent in both oxidation and substitution modes said derivation being based on ambient temperature of said brown stock and said retention time in said reactor means along with other parameters of the method, and comparing BK with a set point reference and changing the injection of said bleaching agent in response to a lack of comparison.

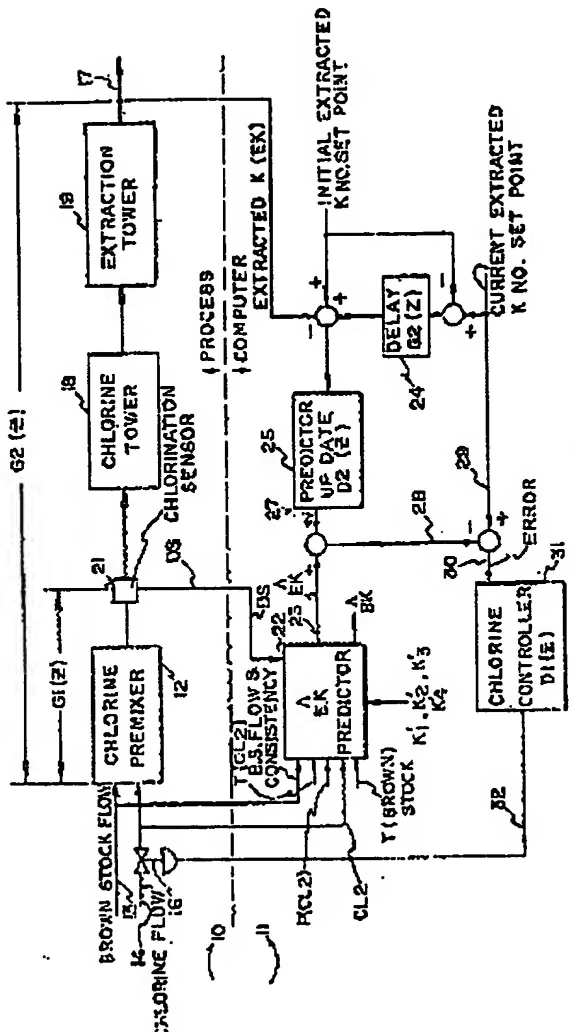

FIG.1

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FIG.2

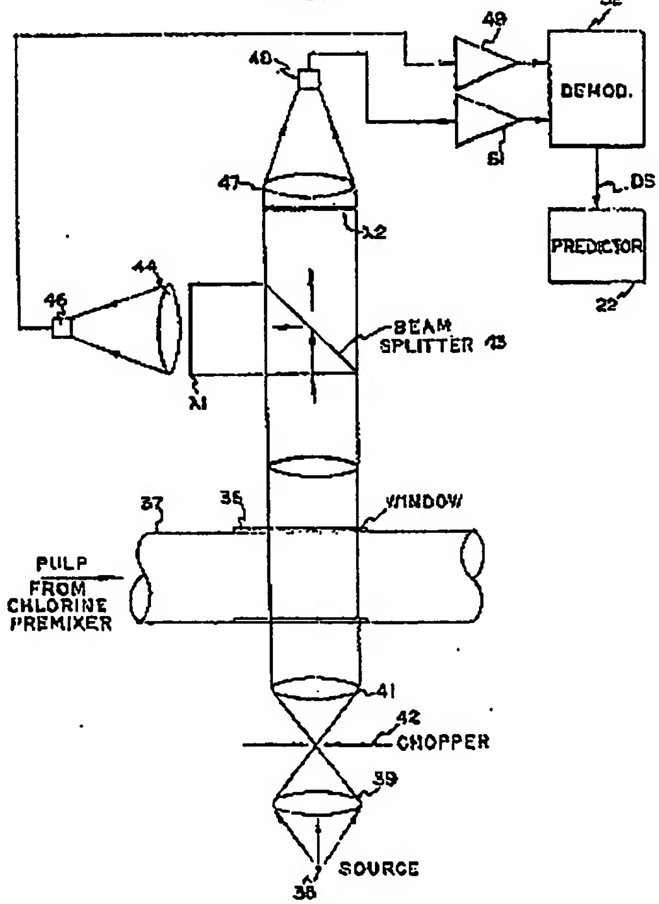

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FIG.4

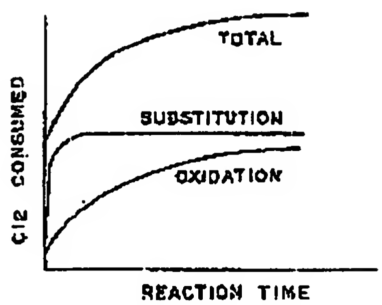
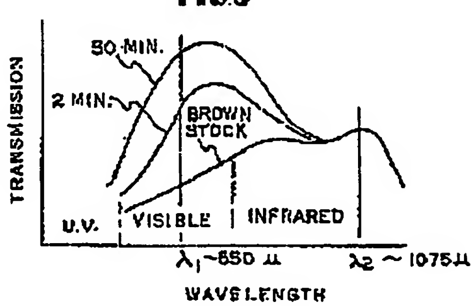


FIG.3



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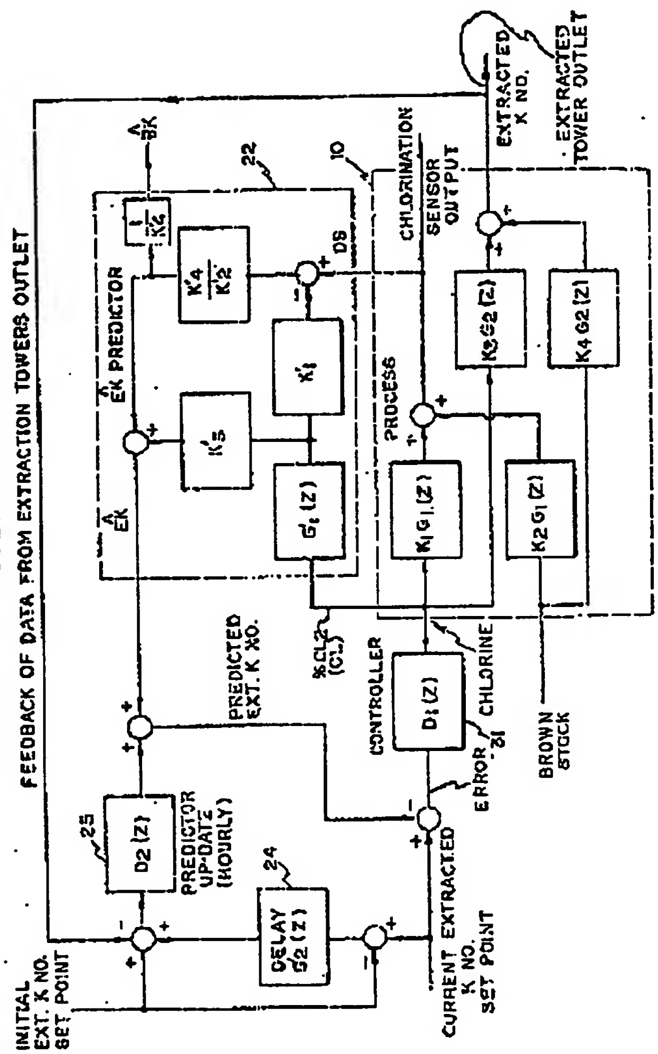

FIG.5

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